PATENT SPECIFICATION

(11) 1237491

1237491

DRAWINGS ATTACHED

(21) Application No. 7609/69 (22) Filed 12 Feb. 1969
(31) Convention Application No. 707 668 (32) Filed 23 Feb. 1968 in
(33) United States of America (US)
(45) Complete Specification published 30 June 1971
(51) International Classification H 01 c 7/10
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H1K 213 226 236 273 287 288 289 290 300 313 341 34Y 353 36Y 422 458 459 460 470 483 52Y 530 53Y 578 579 581 583 604 60X 60Y 611 618 61Y

(54) GUNN-EFFECT DEVICES

ERRATUM

SPECIFICATION No. 1,237,491

Page 1, line 1, *for* "We, RAC RADIO CORPORATION" *read* "We, RCA CORPORATION"

THE PATENT OFFICE
9th August 1971

PATENTS ACT 1949

SPECIFICATION NO. 1,237,491

Reference has been directed, in pursuance of Section 9, subsection (1) of the Patents Act 1949, to Specification Nos. 1,110,338 and 1,161,782.

THE PATENT OFFICE
16 November 1971

R 6414/6

gating with constant velocity toward the anode where it disappears, followed by a new high field domain building up at the cathode, all in a periodic manner.

The phenomenon occurs in semiconductors having a high mobility state that is lowest in energy along with low mobility states at a higher energy level. As the applied electric field is increased, some electrons are transferred from the high mobility state to the low mobility state resulting in an average electron velocity decrease.

By incorporating this device, operating at room temperature, into a radio frequency circuit, microwave power can be delivered to a load.

Previously, Gunn-type devices have been

of them are made simultaneously on a single wafer of semiconductor material. The wafer must subsequently be diced into individual device units. This needs to be done in such a way that damage to the electrode gap is minimized.

According to the invention we provide a Gunn-effect semiconductor device characterised by comprising: (a) a substrate layer of high resistivity semiconductor material, (b) an epitaxial surface layer, on said substrate, of a semiconductor material of the type having a high mobility state which is low in energy and a low mobility state which is high in energy, and which is capable of transferring electrons from said high mobility state to said low mobility state under the influence of an

SEE ERRATA SLIP ATTACHED

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(54) GUNN-EFFECT DEVICES

(71) We, RAC RADIO CORPORATION (formerly Radio Corporation of America), a corporation organised under the laws of the State of Delaware, United States of America, of 30 Rockefeller Plaza, City and State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which is to be performed, to be particularly described in and by the following statement:—

The present invention relates to improved electrode structures for Gunn-effect semiconductor diodes and to an improved method of fabricating the electrode structures.

Gunn-effect devices comprise a uniform single crystal body of bulk semiconductor material with two spaced electrodes. Either a steady state or a pulsed d.c. voltage is applied across the body and when a characteristic threshold voltage is reached or exceeded, current oscillations are produced. The oscillation frequency depends mainly on the transit time of electrons travelling across the gap between the electrodes.

It has been shown that the current oscillations are produced by a region of high electric field building up near the cathode and propagating with constant velocity toward the anode where it disappears, followed by a new high field domain building up at the cathode, all in a periodic manner.

The phenomenon occurs in semiconductors having a high mobility state that is lowest in energy along with low mobility states at a higher energy level. As the applied electric field is increased, some electrons are transferred from the high mobility state to the low mobility state resulting in an average electron velocity decrease.

By incorporating this device, operating at room temperature, into a radio frequency circuit, microwave power can be delivered to a load.

Previously, Gunn-type devices have been made with the semiconductor body in the shape of a small die, and ohmic contacts made to opposite faces of the crystal body. In order to conduct heat away from the body rapidly, metal studs were soldered to one or both ohmic contacts. However, since the amount of heat generated in the device may be relatively large (a power density of the order of a megawatt per cubic centimeter, for example) the relatively long heat path in this type of construction has proved to be unfavourable.

A better heat conducting structure has been provided by growing the semiconductor body as an epitaxial layer on a high-resistivity semiconductor crystal substrate and placing the ohmic contacts in a coplanar manner on the same surface of the layer. This construction provides a better structure for heat transfer through the thin epitaxial layer to the two high thermal conductivity heat dissipators which also serve as ohmic contacts.

However, it has also been found that the coplanar type structure introduces some disadvantages. Electrical characteristics of the device are highly sensitive to surface defects of the crystal and to surface damage that may occur during processing. In order to fabricate the devices in an economical manner, many of them are made simultaneously on a single wafer of semiconductor material. The wafer must subsequently be diced into individual device units. This needs to be done in such a way that damage to the electrode gap is minimized.

According to the invention we provide a Gunn-effect semiconductor device characterised by comprising: (a) a substrate layer of high resistivity semiconductor material, (b) an epitaxial surface layer, on said substrate, of a semiconductor material of the type having a high mobility state which is low in energy and a low mobility state which is high in energy, and which is capable of transferring electrons from said high mobility state to said low mobility state under the influence of an

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electric field, (c) a pair of ohmic electrodes on a surface of said epitaxial layer spaced by a gap of predetermined width, said electrodes having a width less than that of said epitaxial layer so that the lateral edges of said electrodes are spaced inwardly from the lateral edge of said epitaxial layer.

Further according to the invention a method of manufacturing such a Gunn-effect semiconductor device comprises growing a thin epitaxial layer of semiconductor material of desired resistivity on a single crystalline substrate wafer of high resistivity semiconductor material, providing a layer of electrical insulating material on said epitaxial layer, depositing a pattern of ohmic contacts on the surface of said epitaxial layer within openings formed in said insulating material leaving spaces in one direction between said contacts for electron transit gaps, and leaving other spaces in a direction which is transverse to said one direction, for device separation and dividing said wafer into individual devices by making one set of cuts through said ohmic contacts parallel to said gaps in positions remote from said gaps, and another set of cuts through said other spaces between and spaced from said ohmic contacts and transverse to said one set of cuts.

In the accompanying drawings:—

Figure 1 is a cross-section view including a semiconductor wafer in an intermediate stage of processing in the manufacture of a device in accordance with the present invention;

Figure 2 is a plan view of the water of Figure 1 at a later stage of processing;

Figure 3 is a cross-section view taken along the line 3—3 of Figure 2;

Figure 4 is a plan view of a single unit device of the present invention, and

Figure 5 is a cross-section view taken along the line 5—5 of Figure 4.

The following is an example of manufacturing a device in accordance with the present invention using a preferred form of the method of the invention.

As shown in Figure 1, in making devices in accordance with the method of the present invention, one may start with a substrate 2 of gallium arsenide of N type conductivity and having a very high resistivity of the order of, say, 10^8 ohm centimeters. On the substrate is grown an epitaxial layer 4 of N type gallium arsenide having an appropriately low resistivity of 0.5 ohm-cm. and a thickness of 25 microns. The gallium arsenide layer 4 has a resistivity small enough so that the critical $n.l$ product is exceeded. Here n is the per unit volume carrier concentration, and l is the transit gap length. On top of the epitaxial layer 4 is a layer 6 of silicon dioxide which is about 1 micron thick.

Using photoresist, a pattern of openings 8 is made in the silicon dioxide layer 6. As illustrated, the openings are in a pattern of rows and columns and are rectangular in shape. Between each column of openings a column 10 of silicon dioxide is left on the epitaxial layer 4, and in a transverse direction between each of the openings 8 there is left a thin ridge 12 of silicon dioxide. The ridges 12 of silicon dioxide have a width of about 10^{-2} centimeters, for 1 kmHz devices. The wider columns 10 of silicon dioxide may have a width of about 7.62×10^{-2} centimeters.

Within the openings 8, ohmic contacts 14 are now fabricated as follows: a silver-germanium-indium alloy having the composition 90% silver, 5% germanium, and 5% indium, all by weight, is evaporated over the entire surface, including the remaining silicon dioxide and the openings 8. The metal is then alloyed into the openings 8 to complete the ohmic contacts 14. The temperature of alloying carbonizes the remaining photoresist which has been left in place over the silicon dioxide pattern which causes the metal alloy to fall off in those areas protected by the oxide. Any of the alloy remaining on the silicon dioxide is removed by a photoresist/etch process as follows: A second coating of photoresist (preferably Eastman KPR) is first applied. The photoresist is then removed in the regions of unwanted ohmic contact metal covering the silicon dioxide layer. Next, the unwanted metal alloy is etched off the silicon dioxide layer. In the second photomasking process above described, it is preferable to use a photomask which has gaps having a width of only about 3/4 that of the 10^{-2} cm. wide silicon dioxide ridges to prevent undercutting during the etching treatment.

Two sets of saw cuts are now made to separate the wafer into individual devices. Cutting may be done with a 2.54×10^{-2} cm. saw. One set of saw cuts is made across the midpoints of the ohmic contacts 14, halfway between the ridges 12. The other set of saw cuts is made transverse to the first set and down the centres of the 7.62×10^{-2} centimeter wide columns 10 of silicon dioxide. This effectively separates the wafer into individual devices 16 as shown in Figures 4 and 5. Each device may then have silver wires 17 and 18 soldered to the ohmic contacts 14a. It should be noted that the Gunn transit gaps between the ohmic electrodes 14a are protected with silicon dioxide at all times during the processing treatment. This helps to protect the sensitive gaps from surface damage. Further protection is given by making one set of saw cuts through the ohmic contacts far enough away from the gaps to prevent surface damage from the sawing operation, and making the other set of saw cuts through the separation gaps far enough away from the active portion of the gaps so that damage is also eliminated from this source.

Considerable improvement in device operation has been obtained by leaving electrical in-

sulation in ghe transit gaps 12 between the ohmic electrodes since surface burn-out has been greatly reduced.

Good ohmic contacts have also been made by using an alloy composed of about 88 parts by weight gold, about 12 parts by weight germanium and 0.6 parts by weight nickel.

WHAT WE CLAIM IS:—

1. A Gunn-effect semiconductor device characterized by comprising: (a) a substrate layer of high resistivity semiconductor material, (b) an epitaxial surface layer, on said substrate, of a semiconductor material of the type having a high mobility state which is low in energy and a low mobility state which is high in energy, and which is capable of transferring electrons from said high mobility state to said low mobility state under the influence of an electric field, (c) a pair of ohmic electrodes on a surface of said epitaxial layer spaced by a gap of predetermined width, said electrodes having a width less than that of said epitaxial layer, so that the lateral edges of said electrodes are spaced inwardly from both lateral edges of said epitaxial layer.

2. A device as claimed in claim 1, in which the surface of said epitaxial layer within said gap is protected with a layer of electrically insulating material.

3. A device as claimed in claim 1, in which said semiconductor material is gallium arsenide.

4. A device as claimed in claim 2, in which said gap is about 10^{-2} cm. for 1 kmHz operation and said insulating material is silicon dioxide.

5. A device as claimed in claim 1, in which said ohmic electrodes are composed of an alloy of silver, germanium and indium.

6. A device as claimed in claim 1, in which said ohmic electrodes are composed of an alloy of gold, germanium and nickel.

7. A Gunn-effect semiconductor device substantially as described with reference to the accompanying drawings.

8. A method of manufacturing Gunn-effect semiconductor devices according to claim 1, comprising: (a) growing a thin epitaxial layer of semiconductor material of desired resistivity on a single crystalline substrate wafer of high resistivity semiconductor material, (b) providing layer of electrical insulating material on said epitaxial layer, (c) depositing a pattern of ohmic contacts on the surface of said epitaxial layer within openings formed in said insulating material leaving spaces in one direction between said contacts for electron transit gaps, and leaving other spaces in a direction which is transverse to said one direction, for device separation, and (d) dividing said wafer into individual devices by making one set of cuts through said ohmic contacts parallel to said gaps in positions remote from said gaps, and another set of cuts through said other spaces between and spaced from said ohmic contacts and transverse to said one set of cuts.

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1237491 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

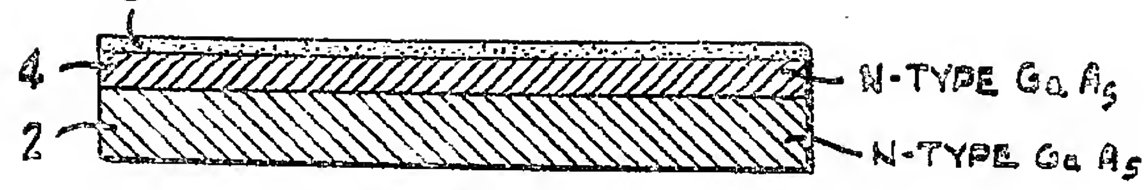

Fig. 1.

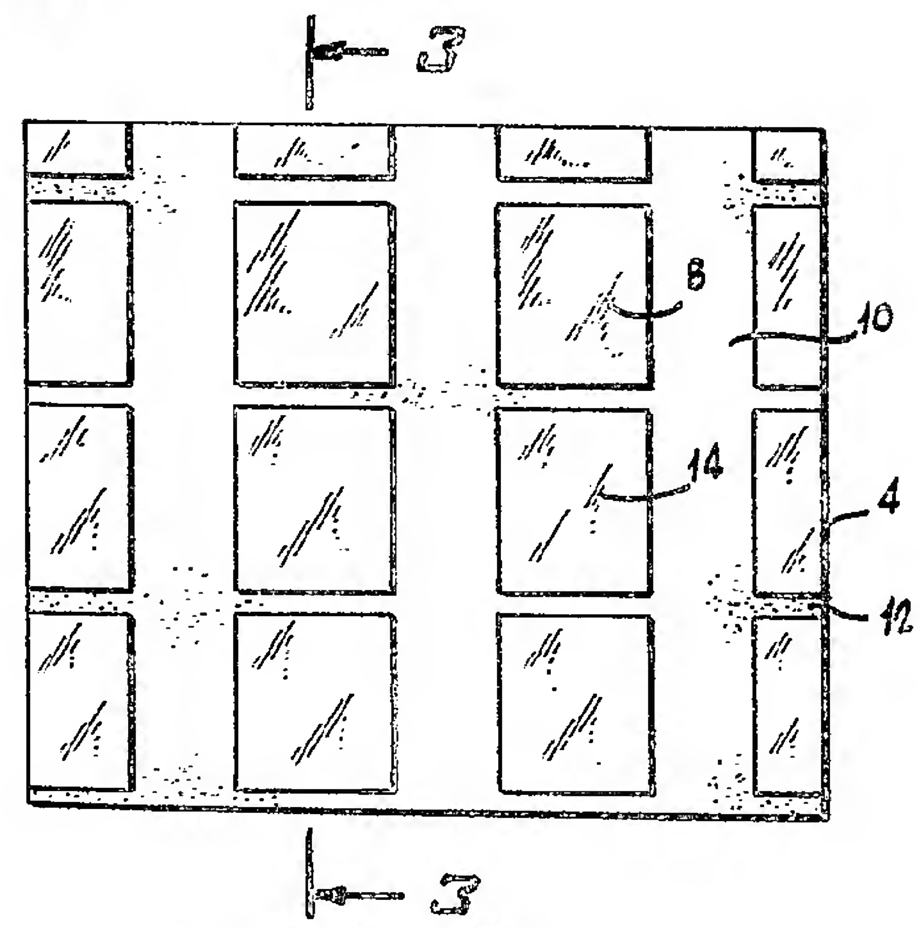

Fig. 2.

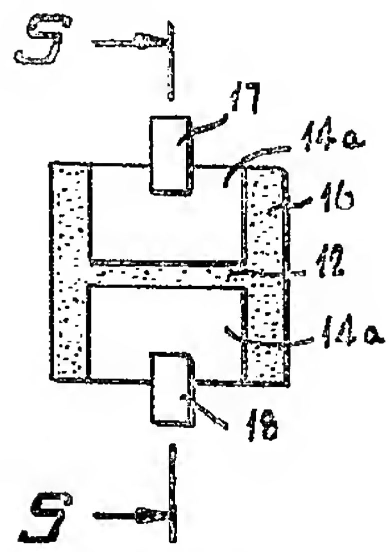

Fig. 4.

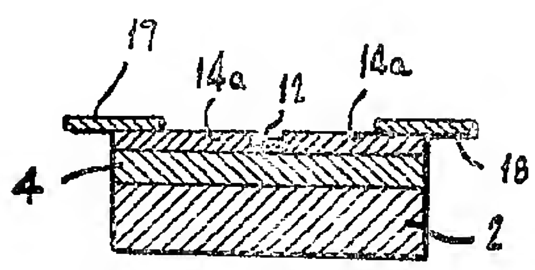

Fig. 5.

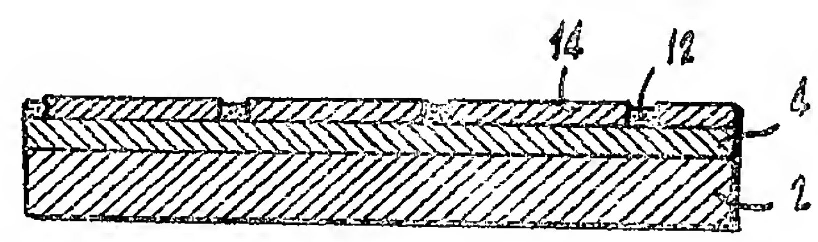

Fig. 3.